AFRL-VS-TR-2002-1515

NWRA-CoRA-02-R213r

Studies of Atmospheric Waves and Turbulence Processes Using Numerical Modeling and Atmospheric Measurements

D. Fritts
J. Werne

NorthWest Research Associates, Inc.
14508 NE 20th St
Bellevue, WA 98009-3027

6 February 2002

Final Report

25 Mar 1998-31 Dec 1999

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
29 Randolph Rd
AIR FORCE MATERIEL COMMAND
Hanscom AFB, MA 01731-3010

This technical report has been reviewed and is approved for publication.

DEAN F. KIMBALL
Contract Manager
AFRL/VSSS

DUANE E. PAULSEN
Deputy Chief
AFRL/VSSS

This report has been reviewed by the ESC Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center (DTIC). All others should apply to the National Technical Information Service (NTIS).

If your address has changed, if you which to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify AFRL/VSIM, 29 Randolph Road, Hanscom AFB MA 01731-3010. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document require that it be returned.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	6 February 2002	FINAL REPORT (3/25/98-12/31/99)

4. TITLE AND SUBTITLE
Studies of Atmospheric Waves and Turbulence Processes Using Numerical Modeling and Atmospheric Measurements

5. FUNDING NUMBERS
PE: 61102F
PR: 2310
TA: BD
WU: AA

F19628-98-C-0030

6. AUTHOR(S)
David Fritts and Joseph Werne

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NorthWest Research Associates
14508 NE 20th Street
P. O. Box 3027
Bellevue, WA 98009-3027

8. PERFORMING ORGANIZATION REPORT NUMBER
NWRA-CoRA-02-R213r

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
29 Randolph Road
Hanscom AFB MA 01731-3010

Contract Manager: Dean Kimball/VSSS

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-VS-TR-2002-1515

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
We find stratification dominates the dynamics in the edge regions of shear layers. Spectral slopes consistent with predictions by Bolgiano (1959) for stratified turbulence are observed during the initial stages of the shear-flow evolution. Only minimal modification to our existing Boussinesq code was required o conduct the gravity-wave breaking simulations. Propagation of the wave during turbulence evolution results in a trail of mixed fluid; unlike the turbulent shear layer which concentrates mixing in a fixed layer Additional funding is required to conduct higher-Re wave-breaking solutions and to further diagnose differences between the wave breaking and shear simulations. Dr. Werne presented work at the European Geophysical Society and the Monterey DOD HPCMO meeting.

14. SUBJECT TERMS
Shear-flow evolution Turbulence processes
Numerical modelling Atmospheric waves and measurements

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

STUDIES OF ATMOSPHERIC WAVES AND TURBULENCE PROCESSES USING NUMERICAL MODELING AND ATMOSPHERIC MEASUREMENTS

I. Project Objectives

Our objectives for the original AFRL project were many. A complete description of those goals is provided in the last R&D status report covering the period September 1998 through September 1999. The narrowed scientific goals of the descoped research effort, extending from March 1998 to December 1999 were:

1. Perform numerical simulations and analysis of Kelvin-Helmholtz (KH) shear instability, assess turbulence structure and its impacts on stable stratification and shear; and
2. Perform initial wave-breaking simulations to address the 2nd major source of shear turbulence in the stratosphere.

II. Progress

Significant advances were made in both research foci under this contract. The first task resulted in the most complete simulations of KH instability and turbulence generation in existence. The first application of these results was in addressing the anisotropic nature of stratospheric turbulence. The degree of anisotropy in stratified flow has been evaluated as a function of depth through the shear layer and as a function of the Reynolds number (Re) for two values of the Richardson number (Ri). We find stratification dominates the dynamics in the edge regions of shear layers. This tendency is greater at higher values of Ri and persists for all values of Re. The dynamics in these edge regions are characterized by entrainment with ambient fluid outside the turbulent layer. As such the value of the effective local Reynolds number is lower than in the turbulent interior of the layer, and the dynamics are dominated by coherent vortex tubes oriented primarily with the streamwise direction near the layer's edge and oriented with the spanwise direction at the layer's edge.

Spectral slopes consistent with predictions by Bolgiano (1959) for stratified turbulence are observed during the initial stages of the shear-flow evolution. However, at later times when turbulence has significantly eroded the primary instability mode (i.e., at a time when one might expect better agreement with Kolmogorov's 1941 predictions than Bolgiano's 1959 predictions), the spectral character of stratospheric turbulence exhibits a slope between that predicted by Bolgiano (-11/5) and Kolmogorov

(-5/3) for the velocity field, but which remains consistent with Bolgiano's -7/5 prediction for the spectral slope of the temperature field. Efforts near the end of the contract began to address the structure functions accompanying sheared turbulence and provided additional evidence of departures from expectations of isotropic homogeneous turbulence. Direct measurements of the turbulence inner scale and comparison with its theoretical dependence on energy dissipation rate nevertheless demonstrated that the theoretical relationship is highly accurate.

Initial studies of wave breaking under the second research task were also completed, but have not been evaluated in the same detail. Because of limited resources, our focus shifted from an anelastic code development to Boussinesq simulations for gravity waves having amplitudes both above and below a convective instability threshold. Simulations at amplitudes below the convective threshold supported the linear stability analysis of Lombard and Riley (1995), suggesting that such motions can lead to instability, but at relatively slow growth rates and having instability structures departing significantly from that anticipated in the linear analysis.

Some time was also spent conducting preliminary 2D tests so that more expensive 3D simulations would employ computer and personal resources optimally. Some preliminary 3D cases were run at lower resolution to understand the morphology of the gravity wave as it began to break down and generate turbulence. Once an understanding of the resolution needs was in hand, our first "high-Re" solution was computed and has recently been completed. As with earlier work, we observe the development of intertwined hairpin vortices at the edges of the unstable regions. Propagation of the wave during turbulence evolution results in a trail of mixed fluid; unlike the turbulent shear layer which concentrates mixing in a fixed layer.

III. Invention Disclosure and Patents Granted

None.

IV. Property/Equipment

Three hard drives and a memory kit for the origin and onyx systems were purchased. These items were placed on the government inventory schedule 12/10/01. The plant clearance case number is S0602A-1311.

V. Personnel Changes, Administrative Actions, Conferences

The supplement allowed for maintenance of a skeleton presence to continue the simulations so the valuable DoD supercomputer resources we have obtained (450,000 T3E this year alone) were not wasted. Dr. Joe Werne presented work at the European Geophysical Society and the Monterey DoD HPCMO meeting.

VI. Travel

Travel to Den Haag, Netherlands and Monterey, CA were required for the conferences attended by Dr. Joe Werne.

VII. Scientific Reports & Presentations

Werne, J. and D. C. Fritts, 1999: Turbulent Stratified Shear Flow: Evolution and Statistics (cover article), Geophysical Research Letters, 26, 439—442.

Werne, J. and D. C. Fritts, 1999: Turbulence and Mixing in a Stratified Shear Layer: 3D K-H Simulations at Re=24,000, European Geophysical Society, XXIV General Assembly. April 1999, The Hague.

Werne, J. and D. C. Fritts, Anisotropy in stratified shear turbulence, Presentation at the 9th DoD HPC User Group Conference, June 1999, Monterey, CA.

Werne, J. and D. C. Fritts, Structure functions in stratified shear turbulence, Presentation at the 10th DoD HPC User Group Conference, June 2000, Albuquerque, NM.